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Digital Control System of Induction Motor Electric Drive of Lifting and Transport Machines.

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❒ ABSTRACT ❒

This paper presents several methods of digital control system of induction motor electric drive for crane, lifts and other hoisting and transporting machines. These methods help to design new digital control systems with desired quality, New programs for microprocessor control system have been created on the base of these methods.

The comparison between the different methods of induction motors control indicates that the system of digital control is the best for its technical, economical and simple in exploitation.

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نظام تحكم رقمي لقيادة المحركات الكهربائية للمصاعد وآلات النقل

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☐ الملخص ☐

يدرس هذا البحث عدة طرق لنظم التحكم الرقمية للمحركات الكهربائية التحريضية المستخدمة في الروافع والمصاعد وآلات النقل والرفع الأخرى.

تساعد هذه الطرق في تصميم نظم تحكم رقمية جديدة بالكفاءة المطلوبة. لقد أنتجت برامج جديدة لأجل المعالجات المكروية تعتمد على أساس هذه الطرق وقد تمت المقارنة بين مختلف الطرق المعروفة للتحكم بالمحركات التحريضية، حيث توصلنا إلى نتيجة مهمة: إن نظم التحكم الرقمية هي الأفضل لما لها من ميزات فنية واقتصادية وسهولة في الاستثمار.

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The greater part of lifting and transport machines operate in periodical, intermittent service. These machines don't need a long time speed regulation. Among them are cranes, lifts, hoists, carriages and single-scope excavators. Usually they need a short time reduction of speed for precise stopping. Thyristor voltage converter with induction motor Tvc-IM Fig. (1) is the most appropriate type of electric drive in this case, because it has more simple power circuit and thryistor control system than frequency converter. TVC-IM has better working characteristics in comparison with P.C. electric drives.

It's necessary to stress that transient performance produces a great impact on the operation of these machines. For instance, stress loads are possible in hoisting machines on mechanical elements while pooling a lagging rope with a scoop or a load being connected. Travelling and rotating machines have long time transient performance with low-frequency oscillations of beam and cargo as well as high frequency oscillations because of air-gaps in gears and elasticity of shafts and ropes. That's why it's essential to treat such speed regulation laws for electric drives which enable to reduce shock loads because of air gaps in gears lagging up to permissible level. These laws must reduce beam and cargo oscillations without reducing of quik operation of hoisting and travelling machines.

Shock loads in gears of such machines is easy to analyze talking into account only double mass system, i.e. motor's rotor and working unit of mechanism, connected with system's equivalent elasticity shafts. Computation and analysis of such systems show that there is a certain rigidness of speed-torque characteristics β_{opt}, when damping factor of oscillations is maximum: [1]

$$\zeta_{max} = 0.5\left(\sqrt{\gamma} - 1\right) \quad \text{while}$$
$$\beta_{opt} = \sqrt{c.J_2}\ \gamma^{3/4}$$

$$\text{where } \gamma = \frac{J_1 + J_2}{J_1}$$

C- rigidness factor of mechanical connections (shaft, rope, beam).

J_1, J_2- moments of innertia of motor and working unit.

when $J_2 > 8\ J_1$, $\xi > 1$ the transient performance of system is exponential, non-periodical. Shock load amplitude is proportional to the difference of motor and mechanism speed at the moment of zero air-gap in gears. That's why the cotrol system must create speed- torque diagram with given rigidness and speed-time diagram with velocities difference unable to produce unpermitted shock loads ($\Delta\omega = 0.05...0.1\ \omega_r$).

for damping the oscillations of a winging load by the transient performance a method is presented, which is based on the fact that the period of the load oscillation depends only upon the length of the rope $\ell : T = \sqrt{\ell / g}$. In accordance with this the starting of the motor must consists of three intervals fig (2). During the first and the third intervals of a half a period time the motor's speed is changing with the constant accelerator ε. During the second interval of time, which is $= \omega_z / 2\varepsilon - T/2$, where ω_z = given working speed, the accelerator is doubled.

By the end of the transient performance, when the speed is equal to ω_3, the defection of a cargo rope from the vertical position is zero. This method is free from measuring, the cargo weigh, and resisting torque, All one need is the data about the rope's length(ℓ). The control problem is in finding out the time intervals and producing conrol signal for motor's speed.

In travelling mechanics of overhead and gautry crans bridges and independent drives of structural legs the synchronization of their needs. The research has shown that the improvment of steady-state and tranient performance is reached with the help of two feed-back loops. The first one is the rigid negative feed- back measuring the error of legs travel.

The second feedback is measuring the derivation of the legs speed error. There is a certain ratio of these feedback factors to provide the needed range of oscillations.

It's clear that to solve several problems, such as reduction of shock stress, damping the oscillations, synchroizing the legs speed, etc. analogue control systems for TVC-IM became too complicated. permits digital control, which provides high precision of driver's regulation, characteristics stability, possibility of steady-state and transeint performances optimisation.

They possess high degree of universality, possibility of quick readjustment by means of changing the software. Digital control can fulfil function of speed, current and distance regulators, aswell as speed controller with changing(algorithem) program.

Functional diogram of such a drive with a speed feed back loop is shown on fig.(3) It consists of three types of elements: analogue-induction motor(IM) with TVC, digital- speed controller(SC), creating speed control signal ω_3 in accordance with technological process and speed regulator(SR), calculating the value of thryistor triggeing angle α; digital-analogue convertor-impulse-phase control system(IPCS); anlogue-digital convertor speed gange(SG).

Steady and dynamical characteristics of induction electric drive with feed back loop are defined mainly by the type and parameters of speed regulator. For the sake of synthesis of digital regulator providing needed quality of operation it's convenient to describe elements of closed loop system by impulser transfer functions.

Induction motor with slip- ringers and TVC, beimg the object of control, approximately may be inroduced by inertial nuit[1]; transfer function of continuos part with zero order fixing unit(FU):

$$H(P) = \frac{K_1}{T_m P + 1} \cdot \frac{1 - e^{-Top}}{P} \qquad (1)$$

where K_1, Tm and To gam factors of continiuospart of system, electromechanical time constant of drive and digital period.

Transformation equation(1) with application of proportional speed regulator with factor Kp gives impulse transfer function of feedback system fig.(1):

$$G(Z) = \frac{K_1 . K_P . \partial_\alpha (1 - a_o)}{Z - a_o + K(1 - a_o)} \qquad (2)$$

where $a_o = e^{-To/Tm}, K = K_i K_p . K_s . \partial_\alpha$ gain factor of open-loop system; ∂_α digital period of thyristor control angle measurement while changing the digital value of the angle for one unit; $K_s = \omega^* / \omega$ - gain factor for speed feedbsck, for analogue-digital gange $K_s = 1/\partial\omega$; $\partial\omega$- digital period of motor's speed measurement.

Characteristical equation root analysis from (2), shows, that the stability of drive with digital time control is reduced. The condition of stable operation of feedback system which is limiting the value of digital period To, will be inequality:

$$To < Tm \ en \frac{K + 1}{K - 1}$$

taking into consideration TVC time-lag(τ):

$$To = Tm \ en \frac{k + 1}{K\left(1 + 2\tau / Tm\right) - 1} \qquad (3)$$

It's obvious that the increase of system gain factor K to increase the speed control range leads to according decrease of digital period To.

Therotical and exprimental results which are obtained gives proof that the digital proportional regulator can provide speed regulation only in range 20...30:1 when $\partial\ \alpha$ is 5 el. degrees and To is 0.01 s. Under this circumstances application of digital control system is not appropriate, because electric drive's contro; qualities remain the same as in the case of analogue control system. In order to increase steady parameters of the electric drive to the greater extent it's necessary to use proportional-integral(PI) regulator, which is described by the transfer function[2]:

$$Gr(z)=\frac{(2Kp+K_iT_o)\left(z+\dfrac{K_iT_o-2Kp}{K_iT_o+2Kp}\right)}{2(z-1)} \tag{4}$$

where Kp and Ki are factors of proportional and integral components.

The presence of integral component makes it possible in the steady-state condition to keep up the speed with accuracy $\pm\frac{\partial\ \omega}{2}$ and speed control range 15-30 times greater than that with proportional regulator.

Besides this, an appropriate choise of coefficient Kp and Ki permits to produce the system with necessary trasient performance. In order to create the system with minimum time-delay and overregulation, it's necessary to adjust the system for module opimum. In this case the transfer function of the open loop system is described by the equation:

$$H_{mo}(P)=\frac{1}{2T_HP}.e^{-T_H P}$$

Where T_H- continuos part total time-delay. It's possible to simplify the last equation:

$$H_{mo}(P)\approx\frac{1}{2T_HP}(1-T_HP),$$

Taking into account fixing factor we get impulse transfer function

$$G_{mo}(Z) = (1 - Z^{-1}) z \frac{1 - T_H P}{2T_H P^2} = \frac{T_o - T_H (Z - 1)}{2T_H (Z - 1)} \quad (5)$$

With such an adjustment limitation of digital period for the sake of stability depends upon only time delay T_H and is independent from other parameters of the drive:

$$T_o < 2T_H$$

Permitted digital period for the sake of the stability in in transient performance[2] can be found from:

$$T_o < T_H$$

To find out speed regulator prameters providing adjustment of the system for module optimum it's necessary to calculate the transfer function motor with TVC within delay:

$$G_1(Z) = (1 - Z^{-1}).z\left(\frac{K_1(1 - T_H P)}{P(TmP + 1)}\right) = \frac{K_1(1 - a_o) + K_1(1 - Z)^{T_H/Tm}}{Z - a_o} \quad (6)$$

considering, that $Gmo(Z) = K_s.G_1(Z).Gr(Z)$, with the help of(4), (5) and(6) we get formulas for calculation of coefficent:

$$K_P = \frac{Tm}{4K_i, K_s.T_H}\left(2 - {To}/{T_m}\right)$$
$$K_i = \frac{1}{2K_i.K_s.T_H} \quad (7)$$

Proportional-integral regulator gives good steady-state performance and system's stability under any speed regulation range. But time delay in digital system, as well as time delay of TVC in analogue systems, leads to big overregulation during step signal of command and disturbance influence. In digital system the value of overregulation may be 20-50 depending from ratio T_o/T_H.

Removal or decrease of this overregulation with simultaneous increase of respond may be achieved in a digital system by changing the

algorithm of regulator in transient performance. In accordance with this algorithm speed regulator workers as proportional- integral only while the speed error is small within the limits of a cetin zone. Outside this zone the regulator should be transformed into relay element, but the value of integral component is memorised. The regulation crated with this algorithem gives good steady-state and transient performances:
high accuracy in keeping the need speed, minimum time delay, small overregulation.

Describe speed regulator gives high accuracy in dynamics while forming start-stop diagrams with different acceleration. It gives possibility to move transport machines strictly for a given distance.

Position feedback loop synthesis is necessary when the grater accuracy of motion is needed. Structure and parameters of position feedback loop are designed in accordance with the fact that internal "slave" speed loop is adjusted on module optimum. Such a regulator can move machine strictly for a given distance in minimum time with maximum precision. Digital speed feedback gives possibility to compute the distance, as a sum of speed digital codes.

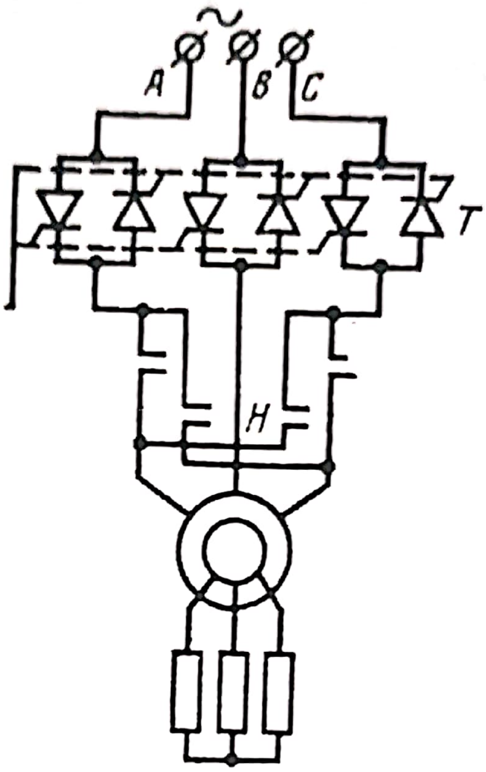
The possibility to solve a wide range of problems with constant functional diagram of electric drive makes it suitable in some cases to design control system with microprocessor fig. (3). Advantages of programmable microprocessor control systems in comparison with diagrams based on rigid logic systems become more visible when it's necessary to realize several functions (speed, acceleration, current limitation, positioning controls).

In this case hardware is the same, but the solution of different problems and parameters is made by software.

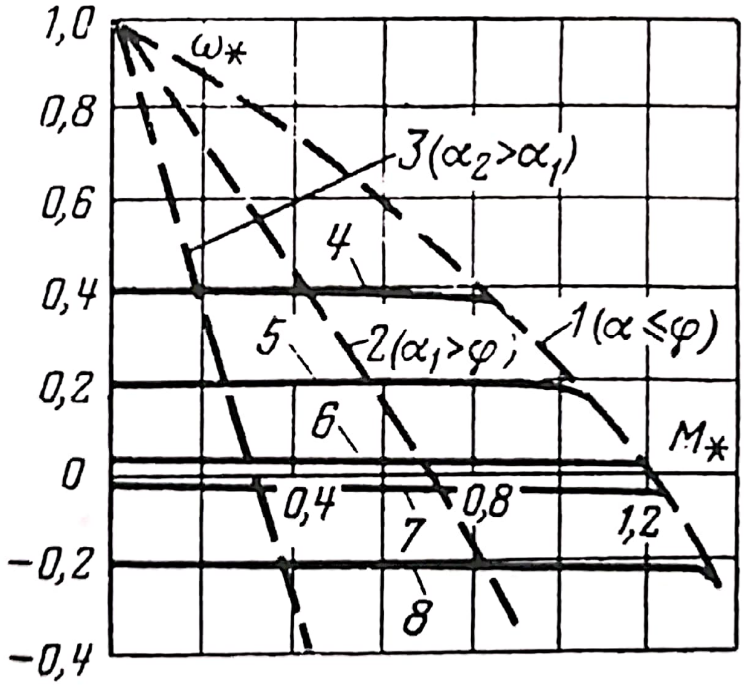
The programs are designed for microprocessor control system based on algorithms for operation of speed regulators. Speed controllers and current limiting units. The system is created on the basis of microprocessor INTEL 8080 with digital speedrange in feedback loop. This digital control system must satisfy high demands to the volume of memory and speed of calculation.

Thus, the synthesis of digital control system for induction motor electric drive with thyristor voltage convertor is presented. It is shown that such a system with proportional-integral speed regulator provide a wide range of speed control (100:1). It permits to change motor's acceleration to the great extent, providing small overregulation and time delay.

The algorithms of speed regulator are designed. The method of calculation of the speed regulator parameters is presented. It is shown that microprocessor control system of TVC-IM gives possibility to solve a wide range of problems with constant hardware. These problems are concerned with control of hoisting and travelling machine drives; wide range of speed regulation of hoisting mechanisms, accurate positioning of travelling mechanisms, protection of mechanisms against shock loads in dynamics, damping of oscillation in the end fig. (4).



(a)



(b)

Fig. (1) thyristor voltage conver tor with induction motor (a) and their characteristic (b).

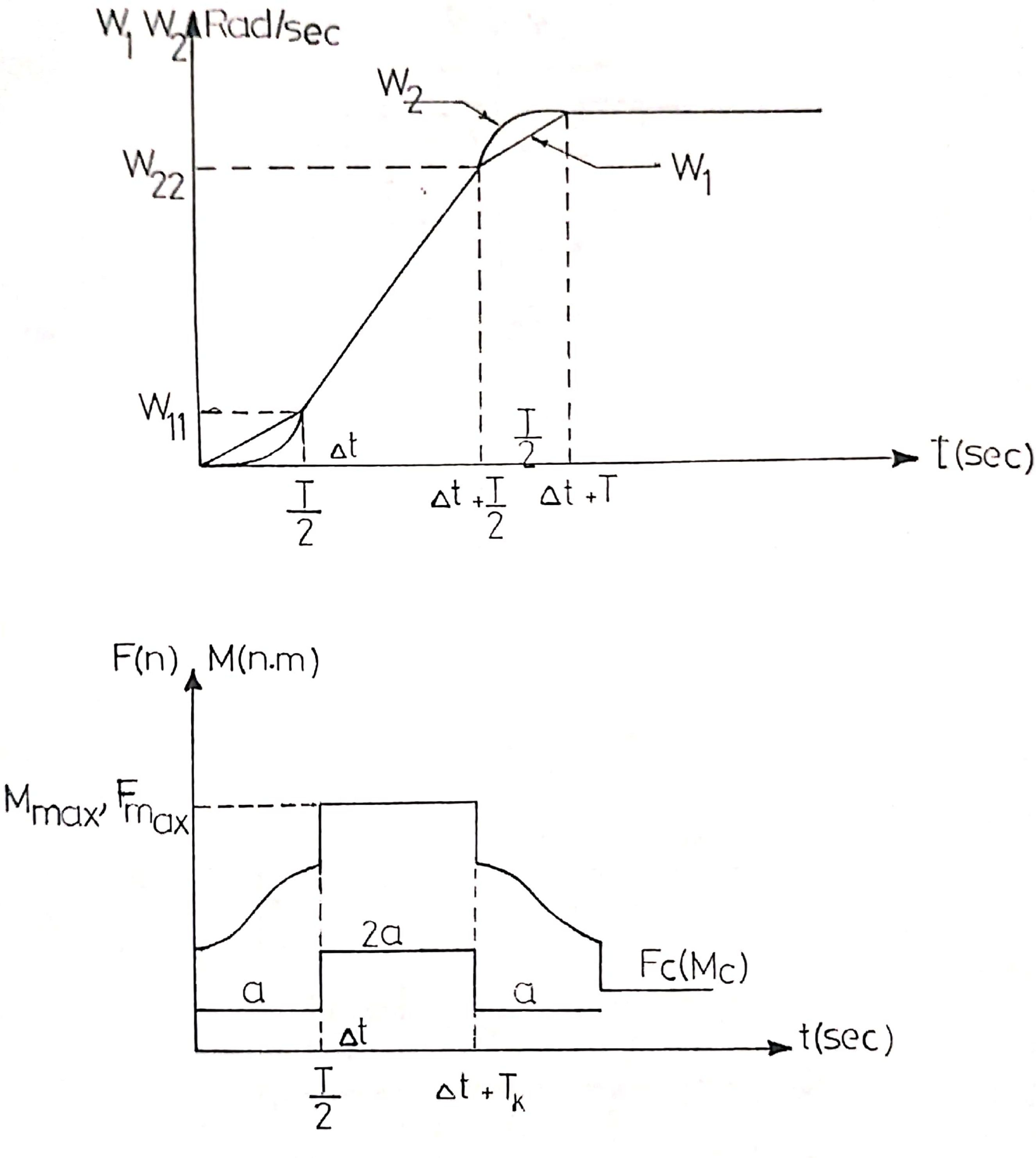


Fig. (2) Algorithem speed for damping the oscillations of a swinging load.

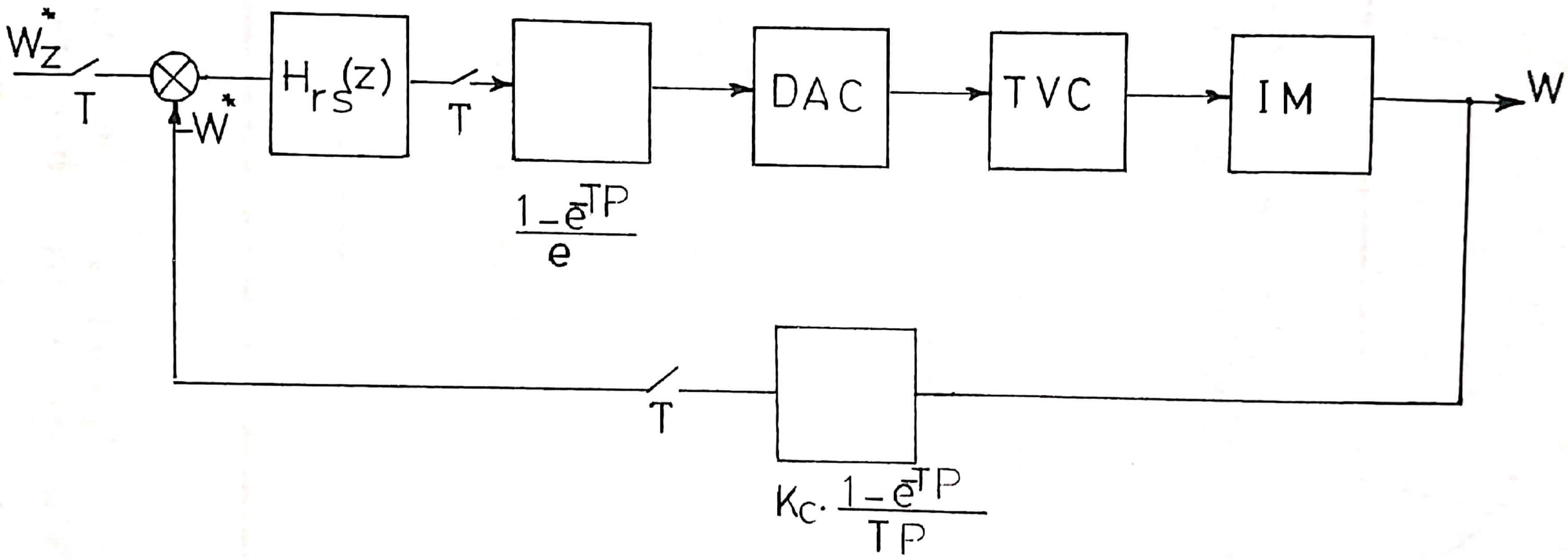
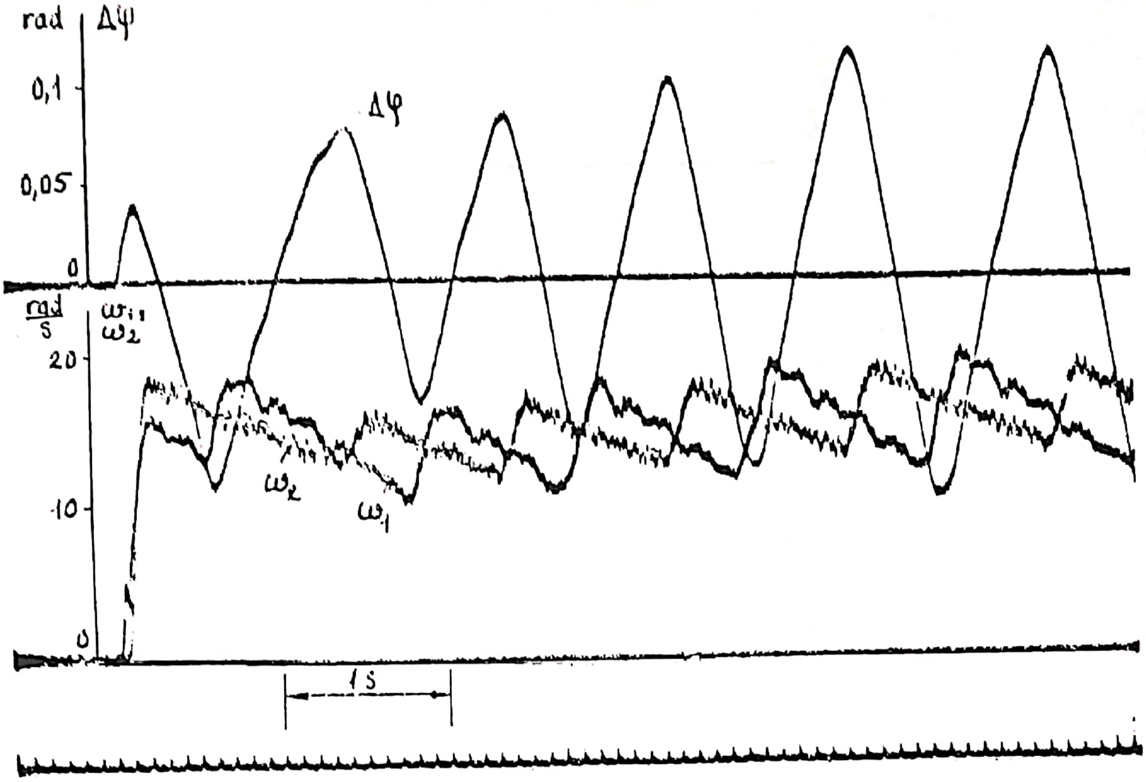
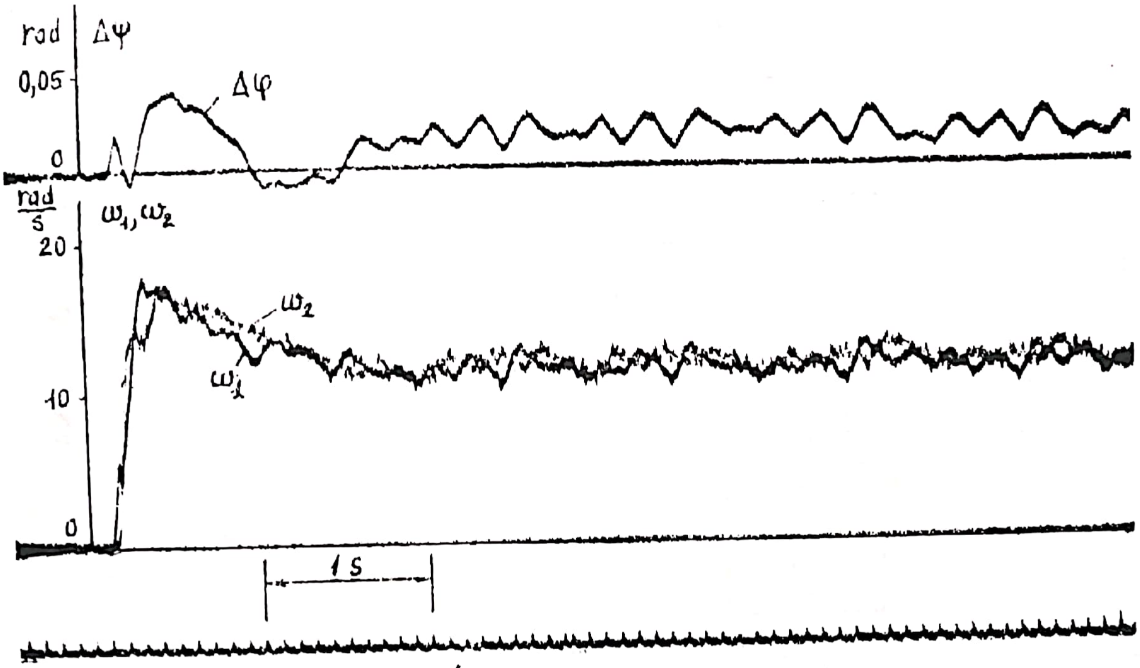


Fig. (3) Speed Regulator



a)



b)

$T_y = 0,I$ s , $K_n = 8,52$ s^{-1}

a – $K_g = 0$; b – $K_g = 2,I3$

Fig. (4) **a- without using algorithms control**
b- with using algorithms control

REFERENCES المراجع

[1]- GERASIMYAK R.P. *Transient performance of induction electric drive for cranes*, Energyatom publishers, Moscow (1982).

[2]- KUO B. *Theory and design of digital control systems machine building*, Moscow (1986)